Measuring Cloud Parameters for In-Flight Icing

by

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Need for Standardization

- Manufacturers and Regulatory Agencies are not cloud physics experts
- Confusing array of equipment available
- Measurements are not being made correctly
- New requirements for SLD measurements

Purpose of This Talk

- Provide organizations with some recommendations on procedures for certification using natural icing conditions.
- No probes of a specific manufacturer are recommended. There are an assortment of probes for all measurements indicated, each having strengths and weaknesses.
- Rapid advances are taking place in instrumentation, so this presentation represents a minimum requirement with today's known instruments.

Design of Measurement Campaign

- Consult an expert
- Avoid mixed phase clouds for simple icing certification
- Use climatologies and expert forecasters
- Select instruments that accomplish objectives

Issues to Address

- What instruments to select?
- How to mount the instruments
- How to calibrate the instruments
- Limitations of the instruments
- Software and processing requirements

What Instruments to Select?

- Requirement to know if you are in Appendix C or outside of Appendix C
- Select instruments that have been evaluated and reported in open literature
- Need for reliable instruments that are well tested (avoid new instrumentation that has not been wind tunnel tested – be skeptical of manufacturer's claims and look for independent testing.)
- Need for some redundancy in critical measurements
- Know each instruments strengths and weaknesses
- Select instruments that can measure with desired accuracy
- Consider the demanding de-icing requirements. Many probes are poorly de-iced.

Parameters to Measure

- Temperature, Altitude, Airspeed, etc
- Liquid Water Content (0-5 g m^{-3})
- Total Water Content (not required but preferred) (0-5 g m^{-3})
- Cloud Droplet Size (2-50 µm)
- Large Particle Size and Shape (50 – 500 µm)
- Icing Rate Indicator (record trips and preferably ramp voltage)
- Icing Rod (photographed)
- Data Acquisition System (1 s resolution)

Onboard Displays

- It is essential to have someone monitor the measurements in real time, for data quality and to guide measurements acquisition.
- Data system must be able to output basic parameters in engineering units in real time, as well as record data.
- In-flight observations are invaluable (e.g. Did probes ice over?)

Concerns

- Are probes adequately de-iced for temperature and liquid waters expected?
- Probe fogging (e.g. rapid descents)
- Probe saturation (e.g. some probes work well at low speeds but the electronics are not fast enough at high speeds to accurately measure all particles)
- Confusion between ice and liquid particles is a big problem for many optical probes, and even hot wire probes.

Mounting of Probes

- All mounting locations should have an engineering assessment (preferably with model backup) that indicate they are suitable
- Probes should be in free stream, out of boundary layer, and not affected by engines, prop wash, and other probes
- For intermediate sized particles (near 100 μm), be concerned about size sorting in the airstream.
- Commonly selected bad locations: Window mounts, top of fuselage near cockpit.

Airflow over F-27:
from King (1984) J. Atmos. Ocean Tech., 1, 5-13.

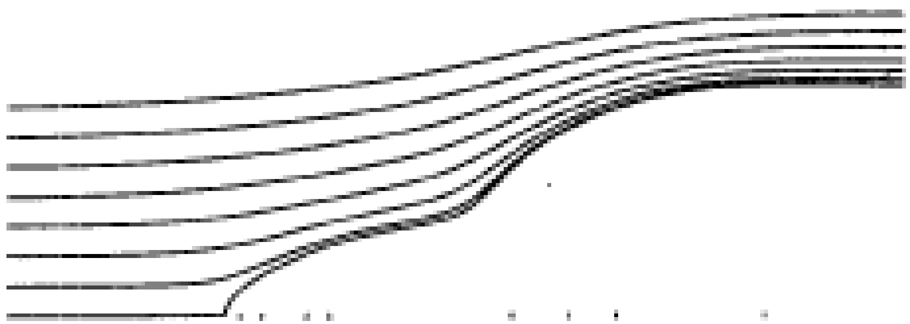


FIG. 4. Streamlines around the simulated shake of Fig. 3.

Streamlines

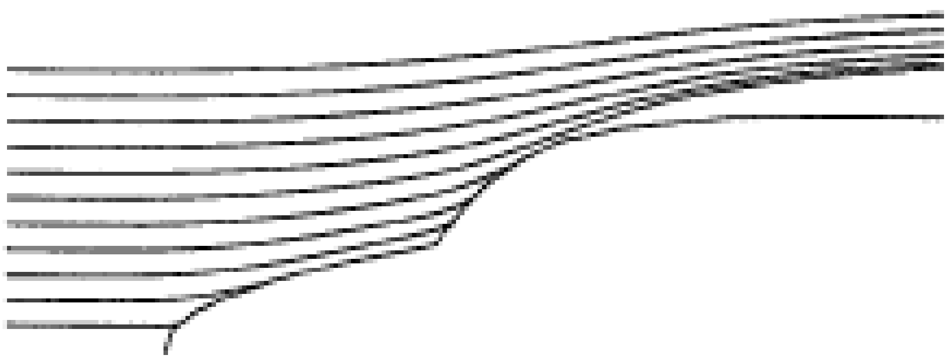


FIG. 6. Trajectories around the F-27 for water drops of diameter 100 μm travelling at 90 m s^{-1}, $\eta = 1.75 \times 10^{-5}$ kg s^{-1}.

Trajectories

90 m s^{-1}

100 μm drops

Instrument Calibration

- Selected instrument types should have calibration data from wind tunnels and other sources over range of temperatures and liquid water contents expected.
- On-site calibrations should be performed as a minimum before and after measurement campaign, and certain instruments should be calibrated on a flight by flight basis (e.g. droplet measuring spectrometer).
- Calibrations should be documented and available for scrutiny by those looking at data
- Adopt calibration procedures reported in the research literature.
- Use redundant measurements to look for bad calibrations (e.g. integrated size distribution versus liquid water probe measurements)

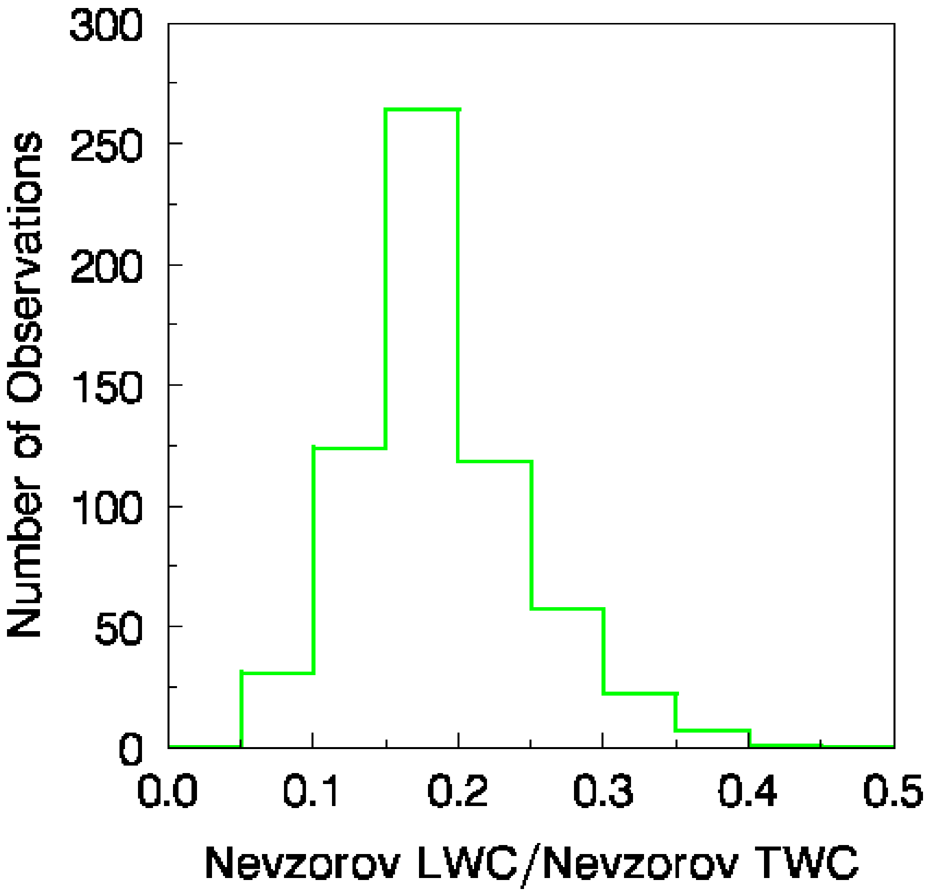
Instrument Maintenance

- Clean optics in optical probes regularly
- Inspect de-icing heaters
- Visually inspect data in real and post time (reference voltages, imagery, probe failures, data acquisition….)
- Run probe simulators (boxes which provide known data simulations of probes)

Limitations of Instruments

- Most conventional cloud physics probes are designed for true airspeeds less than 100 m s-1 and this can cause problems on high speed aircraft.
- Cloud droplet spectrometers can give erroneous results in mixed phase.
- 50 to 100 micron size range is poorly measured by all conventional probes.
- Hot wire liquid water probes detect liquid and a fraction of ice water content.
- 1D Spectrometers cannot be used to detect large drops because of confusion between ice and liquid.
- Fogging and icing can insidiously deteriorate data

LWC Probe Fractional Response to Ice



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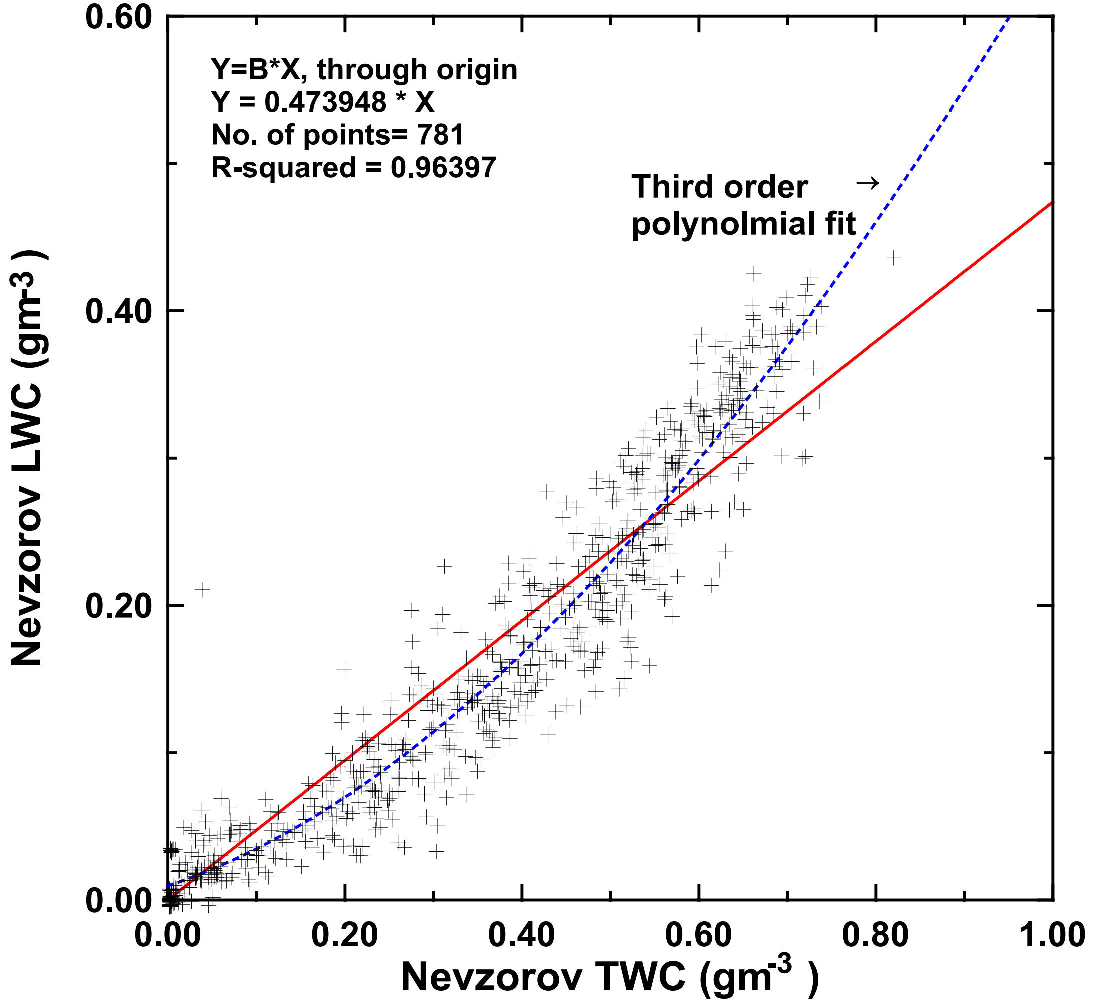
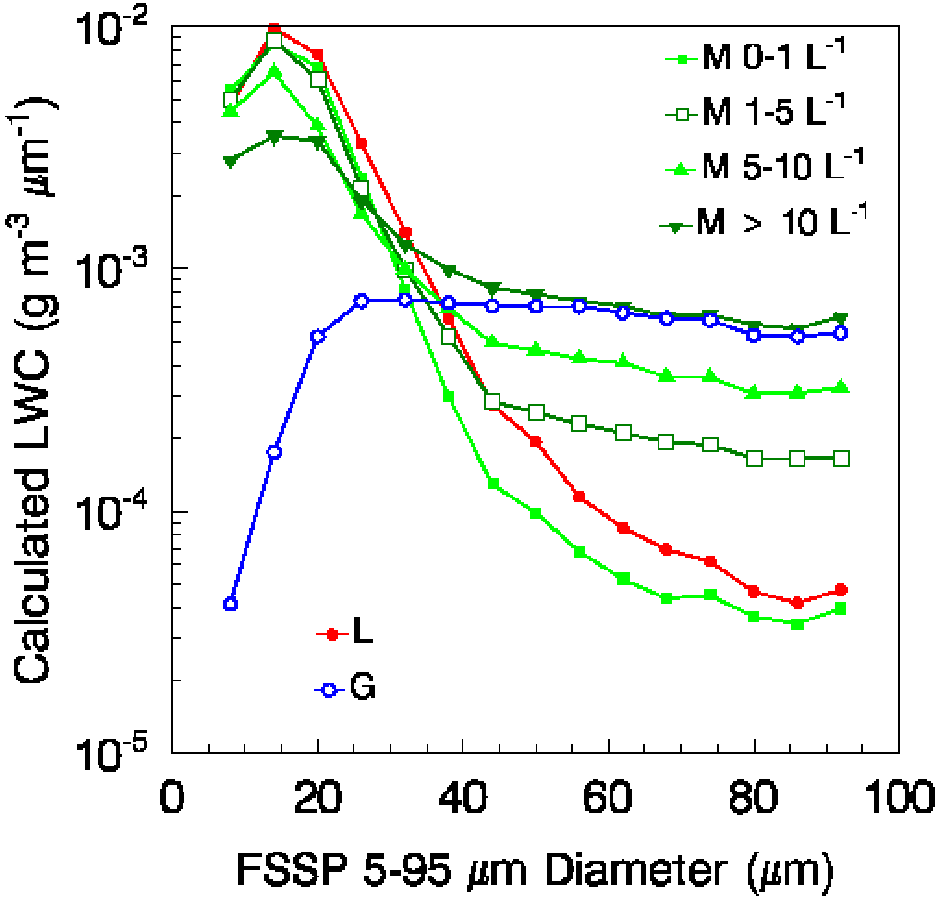


Strapp, J.W., P. Chow, M. Maltby, A.D. Bezer, A. Korolev, I. Stromberg and J. Hallett, 1999: Cloud microphysical measurements in thunderstorm outflow regions during Allied/BAE 1997 flight trials. AIAA 00-0498.

FSSP 5-95 μm Response to Ice



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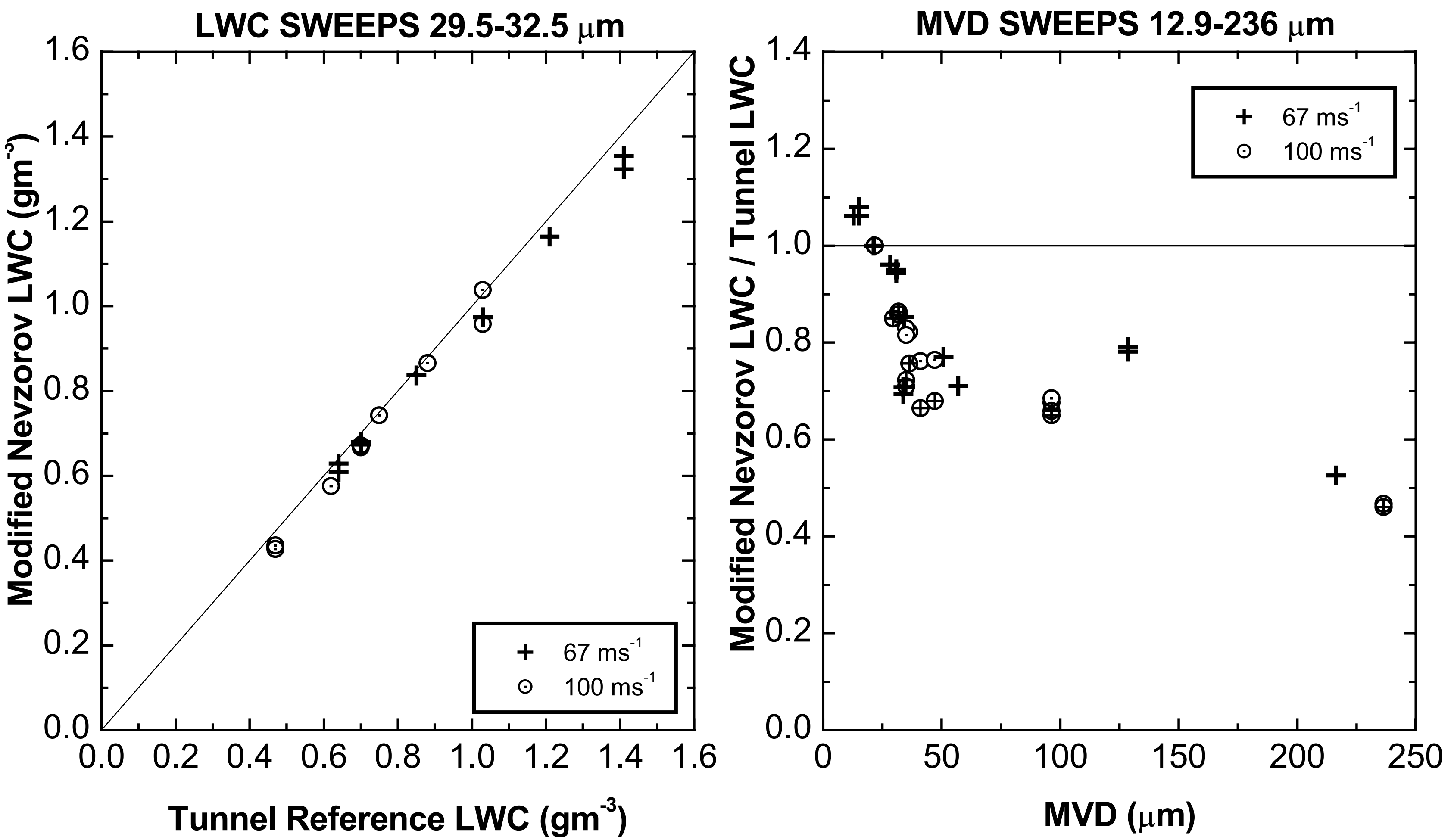
Realizable LWC and MVD Accuracy

- MVD accuracy below 30 microns of 10%.
- MVD above 30 microns. Highly dependent on instrument compliment. Our wind tunnel studies with conventional probes estimate 30%.
- Hot wire liquid water in an all-liquid cloud with MVD less than 40 microns 15%. Droplet spectrometers LWC maybe as poor as 50% based on fundamental calibration errors.
- Above 40 microns hot wire LWC accuracy depends on wire and must be determined in wind tunnel.



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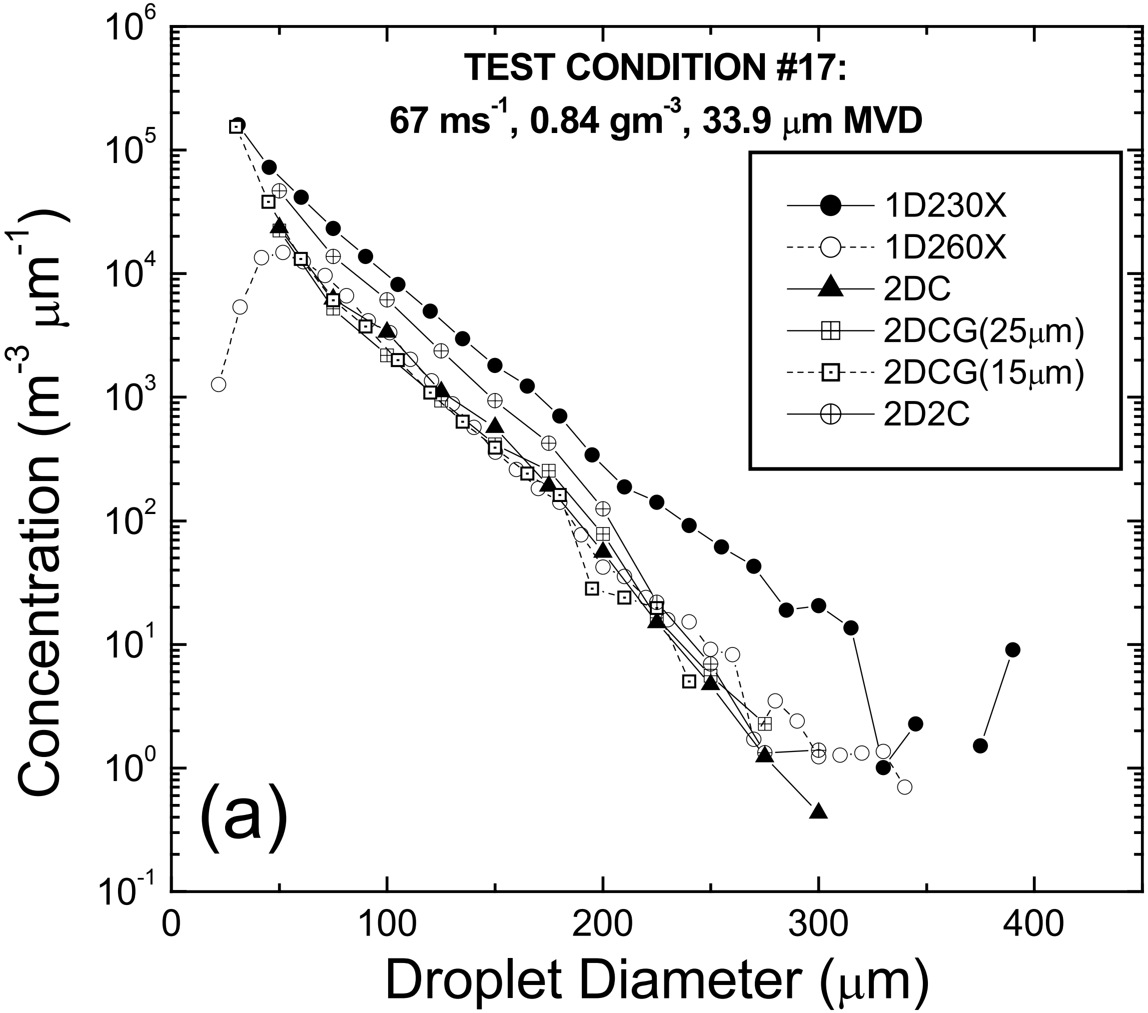

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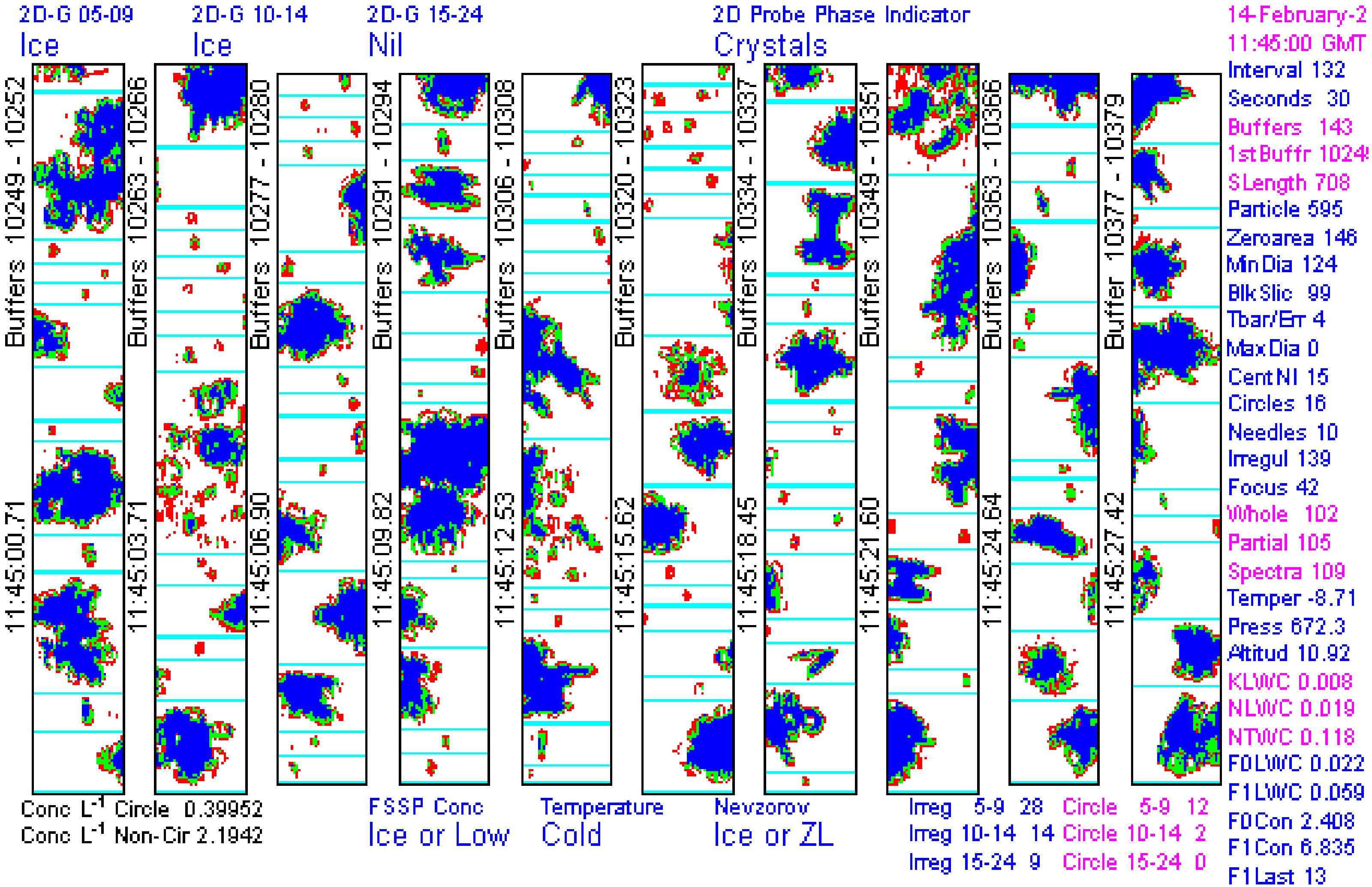
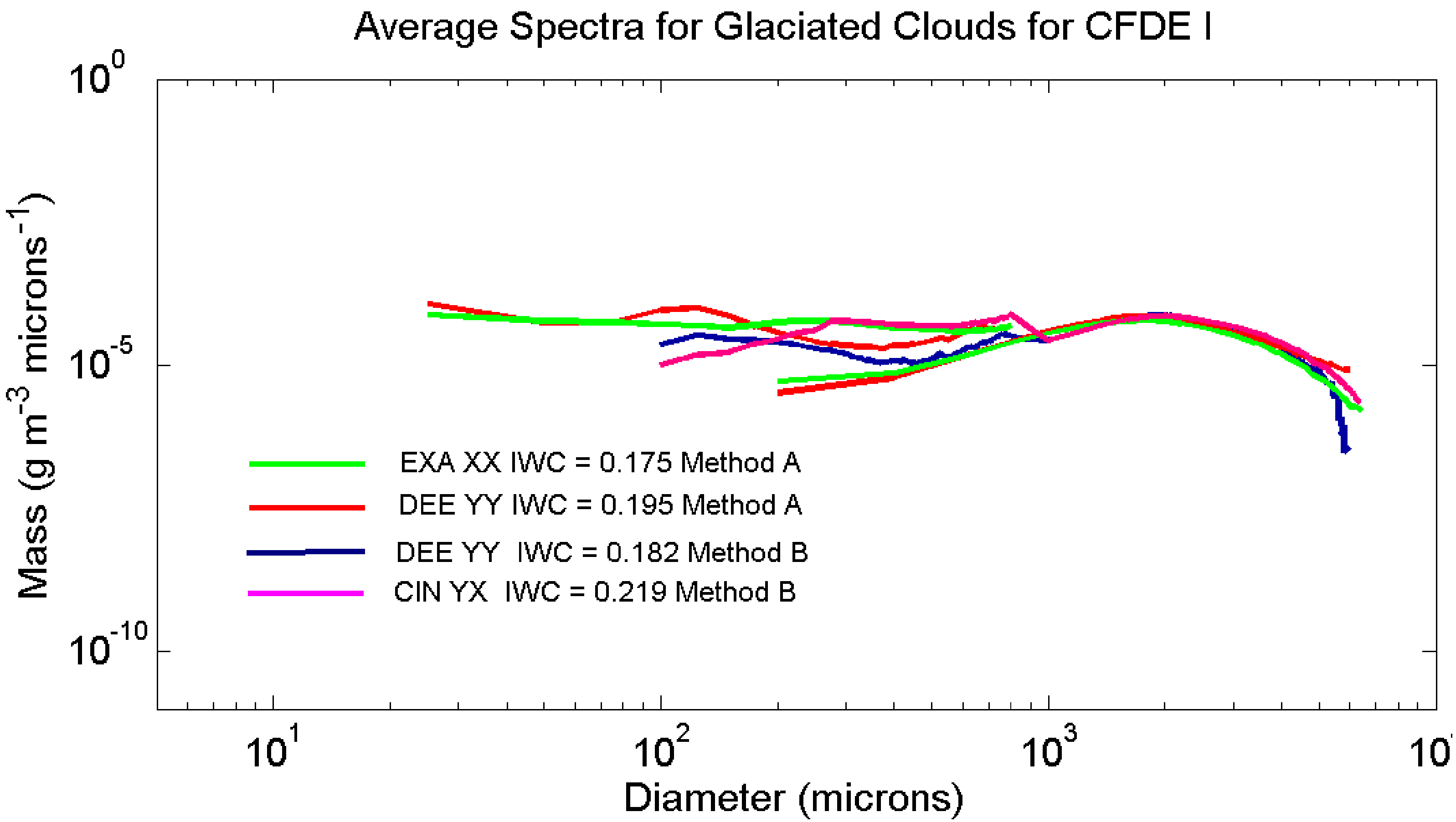
Software and Processing Requirements

- Adopt software processing techniques reported in manuals and scientific literature.
- Beware of analysis of mixed phase cases

Temperature: -9°C; Altitude: 11 kft; Total Water Content: 0.11 g m^{-3}



Scale: 1600 microns


Average Spectra for Glaciated Clouds for CFDE I
Mass (g m-3 microns-1)
10^0
10^-5
10^-10
10^1
10^2
10^3
10^4
Diameter (microns)
EXA XX IWC = 0.175 Method A
DEE YY IWC = 0.195 Method A
DEE YY IWC = 0.182 Method B
CIN YX IWC = 0.219 Method B

Analysis Technique	Circular Particles	Irregular Particles	Method	IWC $g\ m^{-3}$
DEE	X	Y	A	.196
EXA	X	X	A	.175
DEE	Y	Y	B	.182
CIN	Y	X	B	.219
DEE	Y	X	B	.298

Conclusions

- Consult experts in instrumentation, weather forecasting.
- Use instrumentation suited to task
- Mount instrumentation appropriately
- Calibrate instrumentation
- Use appropriate software and analysis techniques
- Keep current - because knowledge regarding instrumentation, software and analysis techniques are evolving.